MODELING AN INTELLIGENT CONTROLLER FOR ANTI-LOCK BRAKING SYSTEM

Digvijay K. Yadav
School of Mechanical Engineering
Galgotias University
U.P, INDIA
Digvijay12691@gmail.com

Abstract— **Antilock braking system (ABS) is able to stop a vehicle wheel without locking and it also decreases the stopping distance. This paper is all about the development of an Antilock Braking System (ABS) using quarter car model and a control methodology is developed to represent an ABS. Now a day's Anti-lock braking system (ABS) is an essential part in vehicle system to produce additional safety to the vehicle and the passengers. To deal with the strong nonlinearity in the design of ABS controller, in this paper an intelligent controller is purposed. The controllers such as Bang-Bang, PID and Fuzzy logic are purposed to control the longitudinal slip and stopping distance of the wheel. Comparison results between these controllers are generated using Matlab/SIMULINK.**

Key words — **Anti-Lock Braking System (ABS), PID, Fuzzy Logic controller, quarter car model, SIMULINK.**

I.   INTRODUCTION

The aim of Anti-lock Braking System (ABS) is to generate in real time the largest possible brake force while keeping the vehicle maneuverable and avoiding excessive wheel slippage. Antilock braking system (ABS) not only prevents the wheel slip problem, but also helps the driver to keep safely control of the vehicle. It also minimizes the stopping distance and eventually, enhances the ability of steering the vehicle. Since ABS introduction in the 1950s, various control structures have been developed. The main goal of all control methods is achieving satisfactory performance for ABS which has been developed or is under research. During designing of an ABS the nonlinearity in the vehicle braking dynamics, variation of model parameters over a wide range due to variation of road surface and vehicle conditions, operation of controller at unstable equilibrium point in an optimal performance and uncertainty of sensor signals creates problem. Because of these parameters many difficulties arise in design of a controller.[1]-[3] PID controller is a traditional controller which is widely used in process control because it has the characteristic of small amount of calculation, good real time and easy to implement etc.

Another suitable control methodology to tackle these problems is fuzzy control (FC). In spite of the absence of analytical modeling information, systems governed by fuzzy controllers are often highly robust [4] and because of their effectiveness at handling the uncertainties and nonlinearities associated with complex systems such as antilock braking systems, they are another suitable option to be chosen [5]-[6].

When braking force is applied to the rotating wheel, it begins to slip, that means the wheel circumferential velocity (V_w) will become less than the vehicle velocity (V_v). Slip (λ) is defined as the difference between vehicle velocity and wheel circumferential velocity, normalized to vehicle velocity. [7]

$$\lambda = \frac{Vv - Vw}{Vv}$$

If more braking force is applied, wheel will slip and wheel gets lock up. A locked wheel does not provide any lateral stability. The relation between slip, vehicle velocity, and the coefficient of friction (μ) is complex, nonlinear and changes with different road conditions, different vehicle speeds, and tire types. Fig. 1 shows typical lateral and longitudinal coefficients of friction as a function of wheel slip [7].
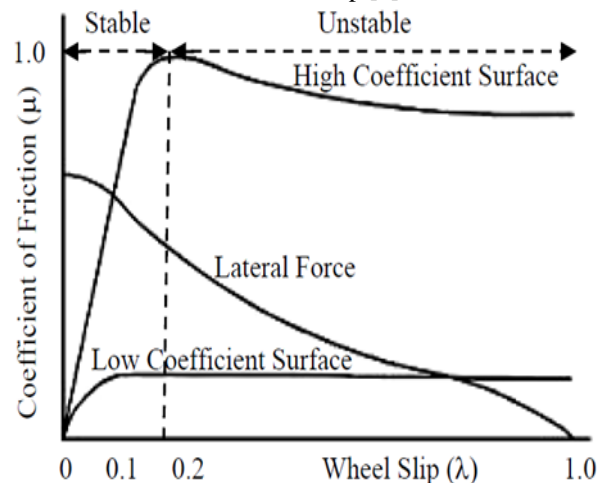

Fig 1 Coefficient of friction (μ) versus wheel slips (λ)

The longitudinal coefficient of friction is zero at $\lambda=0$ and for most road conditions, as λ increases, it increases to a point (peak value) where μ start to decrease as slip increases. If braking force is not quickly removed at this point, the reduced road force leads to a rapid increase in slip and results in wheel lockup. The sensors of Anti-lock brake systems sense this point and reduce braking force so that lockup is avoided. It is ideal to maintain the wheel slip at .2 because it gives maximum value of coefficient of friction μ. Most control strategies define their performance goal as maintaining slip near a value of 0.2 throughout the braking trajectory. This shows a compromise between lateral stability, which is best at zero slip and maximum deceleration, which usually peaks for some value of slip between 0.1 and 0.3. The aim of ABS control is to maintain wheel slip to a known and desired level.

A.   Problem Description

In this paper, controllers for ABS according to Figure 2 are designed such that the input variables to the controller are obtained by wheel speed and vehicle acceleration sensors. The tuning of PID controller is manual. All parameters of membership functions and rules of the fuzzy system that is Takagi- Sugeno-Kang (TSK) type are obtained using the fuzzy

logic. The objective function is defined to maintain wheel slip to a desired level so that maximum wheel tractive force and maximum vehicle deceleration are obtained. Then the simulation results of each controller are compared and best controller is purposed.
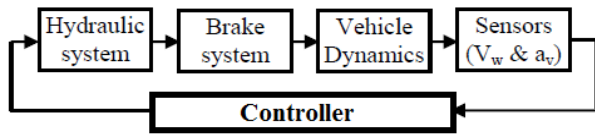

Fig 2. Block diagram of the proposed ABS

II.   VEHICLE DYNAMICS

In this paper a quarter car vehicle model undergoing perfectly straight line braking maneuver has been taken. Thus there is no lateral tire force & also yaw do not exist.[8]

The following assumptions are considered in the modeling process:

a)   Without steering input.
b)   Only longitudinal vehicle motion.
c)   The sprung mass is assumed to be connected to unsprung mass with a rigid body (no damping effect)
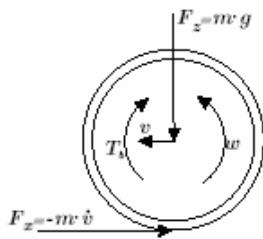d)   Approximating the vertical forces as a static value.

Fig 3 Quarter car or Single wheel model

The equation of motion is:
$$v = - F_x / m \ldots \ldots \quad (1)$$
$$\omega = (R\ F_x - T_b) / J \ldots (2)$$
The tire friction force is given by the coulomb's law
$$F_x = \mu\ (\lambda)\ F_z \ldots \ldots (3)$$
The longitudinal wheel slip is given by
$$\lambda = v - \omega\ R / v \ldots \ldots (4)$$

Where, F_x : Tractive force, F_z : Vertical load, T_b = Braking torque, v: vehicle absolute velocity, m: quarter vehicle mass, μ:coefficient of friction, ω: wheel angular speed, R: rolling radius of the wheel, J = moment of inertia of the wheel.

III.   HYDRAULIC BRAKE DYNAMICS

It is known that, the rate of change of brake pressure (or brake torque) is proportional to fluid flow rate, and flow rate is proportional to control valve opening. Therefore, the brake pressure rate is proportional to the valve command. [9]
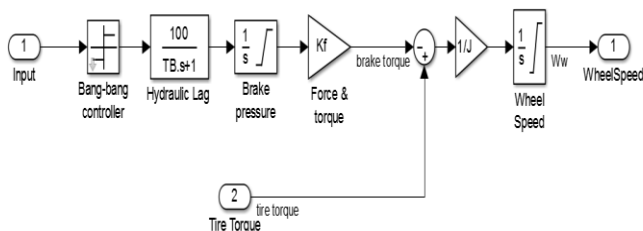

Fig 4 Brake Dynamics in Simulink
IV.   BRAKING SYSTEM WITH ABS

1.   PID Controller

PID control algorithm as a conventional control method is widely used in process control because it has the characteristic of small amount of calculation, good real time and easy to implement etc. PID controller is one of the traditional controllers developed to calculate the errors obtained from the actual model with the desired input. PID controller includes three types of parameters which is adjustable according to the errors. Every parameter functioned in different technique in order to reduce the errors from plant model. PID controller can be described as

a) P = proportional
b) I = Integral
c) D = Derivative

P represents the errors that occurred in current condition,
 I represents the errors gathered from past condition and
D represents the prediction of future errors based on the changes occurred during current condition.
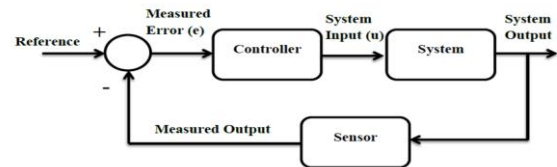

Fig 5 Block Diagram of Feedback Control System

2.   FUZZY Controller

In recent years, Fuzzy Control is an intelligent, knowledge based control methodology which performs exceptionally well in nonlinear, complex and even in the case of not mathematically describable systems. Thus the use of fuzzy logic for an antilock-braking system (ABS) seems to be most promising.
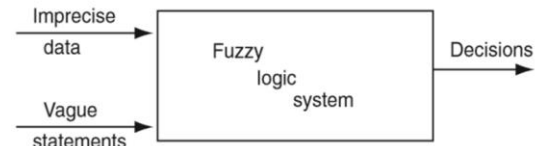

Fig. 6 A fuzzy logic system [10]

Need for Fuzzy Logic in ABS:
   Without using fuzzy ABS, the braking pressure in the braking system reaches a very high level and the wheels lock within short distance. These results in an unstable behavior, the vehicle cannot be steered anymore and the stopping distance increases.
   With fuzzy ABS controller activated, steer ability is not only retained during the whole braking maneuver, but the slowing down distance was considerably shortened as well.

Fuzzy Logic controller:
Every fuzzy controller contains three main components:
   a.   Fuzzification,
   b.   Rule base
   c.   Defuzzification mechanisms.
The fuzzification mechanism is to map the controller inputs and assign a proper value $\mu\ (u)$ for each proper function forming the universes.
Fuzzy rule base consists in assessing fuzzy rule set of the type, which has two main parts, the antecedent and the consequent.
   IF e (t) IS …AND ce (t) IS… THEN u (t)

The antecedent is before the word "THEN" and its function is to relate the controller input proper values to the consequent. Defuzzification is the procedure through which the fuzzy rule set is assessed and a non-fuzzy or analog signal is assigned. The most frequently used method is the area center, although there are methods like the first maximum or the maximum average.

In this work, Fuzzy Logic Controller is developed based on Takagi-Sugeno-Kang (TSK) model. There are two inputs given for this controller which is obtained from the ABS model using PID controller. PID controller function as a bench mark for fuzzy, it's a conventional controller and very easy to identify fuzzy parameters.[10]
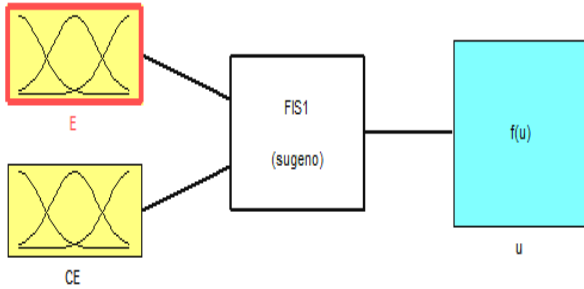

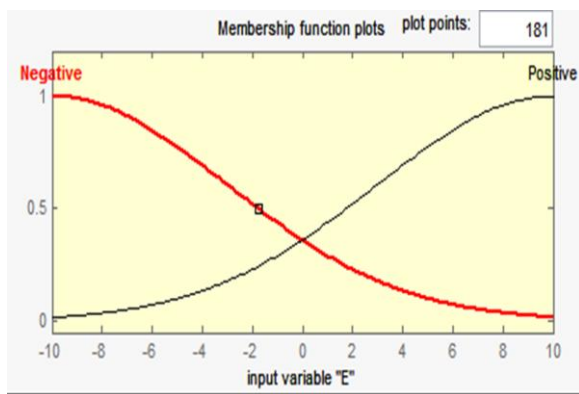**Fig 7 Fuzzy logic control block**

Fig 8 Error input variables

The maximum and minimum range inputs for fuzzy logic is defined based on the PID controllers. The output of the fuzzy logic will be the electrical current which will be the input for the hydraulic lag transfer function. The input variables can be divided into 2 variables which is positive and negative. Where else, output variables are 3 that are Max, Zero and Min. In order to improve fuzzification speed, Gaussian function is chosen as the membership function.
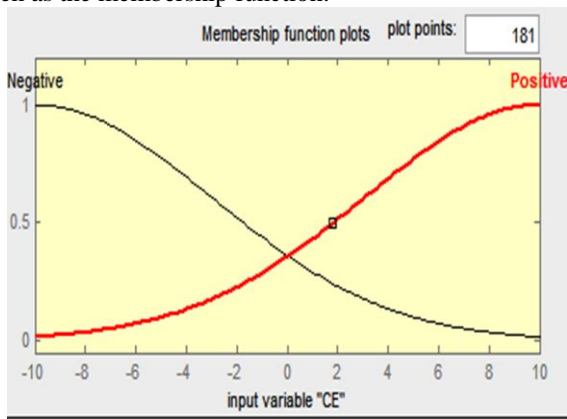

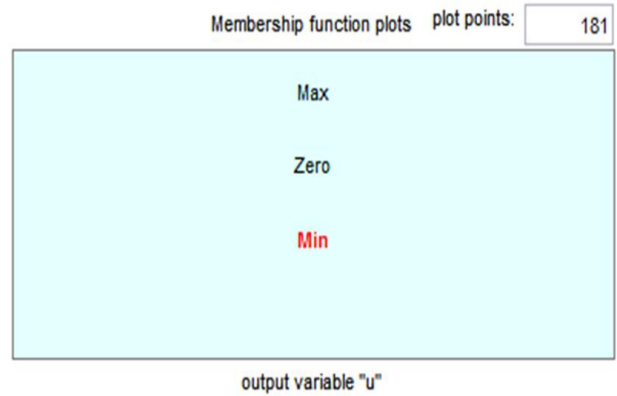**Fig 9 Change in Error input variables**

Fig 10 Current output variables

1. If (E is Negative) and (CE is Negative) then (u is Min) (1)
2. If (E is Negative) and (CE is Positive) then (u is Zero) (1)
3. If (E is Positive) and (CE is Negative) then (u is Zero) (1)
4. If (E is Positive) and (CE is Positive) then (u is Max) (1)

Fig 11 Rule Table

The method used for solving the FIS is well-known inference method Sugeno or Takagi–Sugeno–Kang method of fuzzy inference process. This method was introduced by Sugeno (1985).[10]

V. SIMULATION PARAMETERS

Quarter car vehicle model and vehicle brake model is developed in SIMULINK. The technical specifications of the quarter vehicle model are listed in table.

Table 1: Simulation Parameter

Symbol	Quantity	Value
m	Quarter Vehicle mass	375 Kg
g	Acceleration Due to gravity	9.81 m/s^2
R	Radius Of Wheel	0.326 m
J	Moment of inertia of wheel	1.7 Kg-m^2
v	Initial Vehicle Velocity	30 m/s^2
Pb_{max}	Maximum Braking Torque	1500 Nm
T_b	Braking Torque	0.01 Nm
λ_d	Desired Slip	0.2

VI. SIMULATION RESULTS

The Figure 12 to 16 shows the comparison of input brake torque applied to the quarter vehicle brake model. The comparison is between without ABS braking and ABS results where by the ABS with three types of controllers. Based on the results, fuzzy controller has the optimum results compared to the other controllers. The stopping distance reduced compare to PID controller. Same is true for wheel speed and vehicle speed.

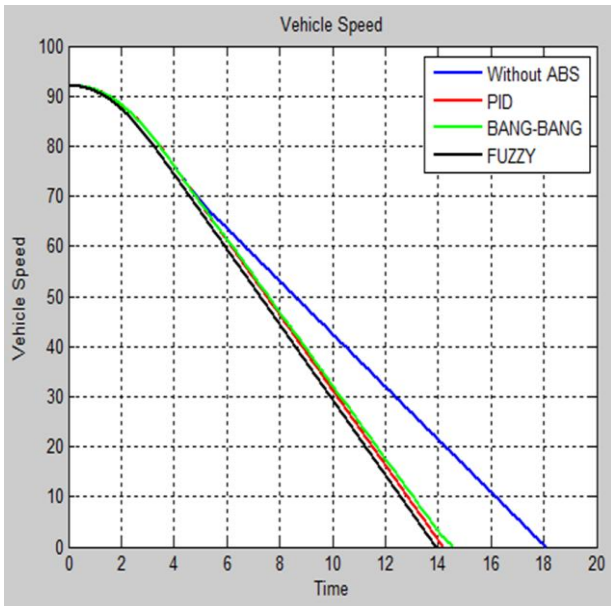### 1) Vehicle Speed Vs Time

Fig 12 Comparison of Vehicle speed

It clearly shows that without ABS model the vehicle takes 18 seconds to come at rest. As we implement the ABS model it decreases. From Bang-Bang to the fuzzy controller model the time to stop the vehicle decreased to 13.8 seconds.
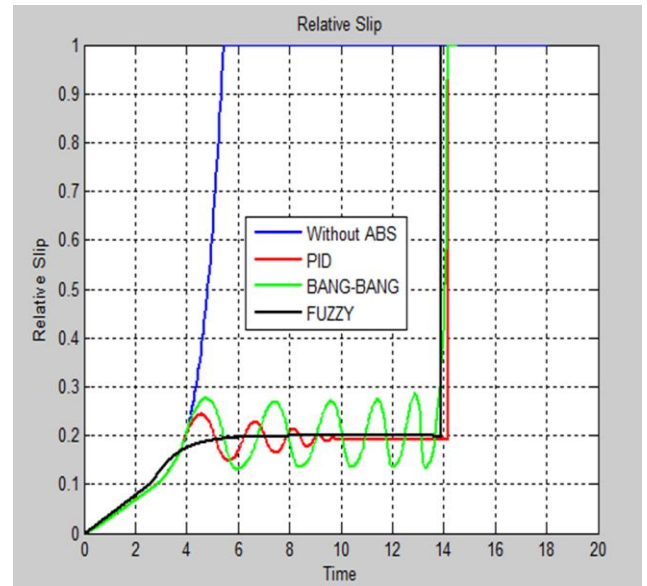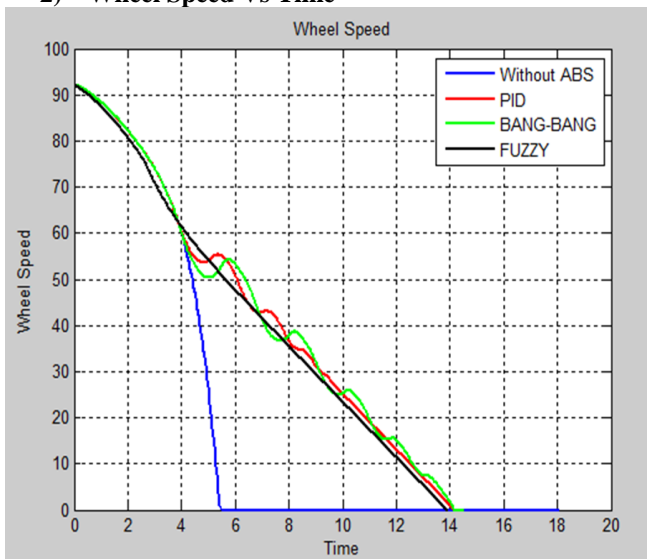
2) Wheel Speed Vs Time

Fig 13 Comparison of Wheel speed

When we implement the Fuzzy controller in ABS the wheel speed is following the vehicle speed in same manner without any rise and fall in speed.

3) **Relative Slip Vs Time**

Fig 14 Comparison of Relative Slip

When we implement the Fuzzy controller in ABS the slip is accurately .2 after 6 seconds without any oscillation and it remains same until the vehicle is not stopped, which is our desired output.
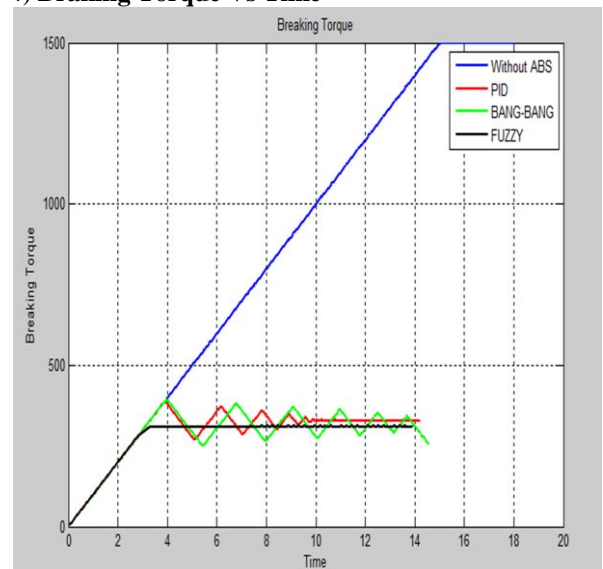
4) **Braking Torque Vs Time**

Fig 15 Comparison of Braking Torque

It is clearly shown from the fig that for Fuzzy controller the braking torque is about 310 Nm for long period of time with very less or no oscillation
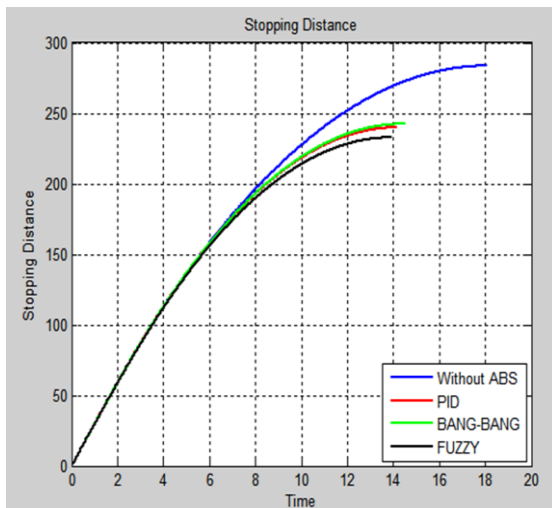
5) **Stopping distance Vs Time**

Fig 16 Comparison of Stopping Distance

It is clearly sheen from the fig that Fuzzy controller is the best controller among all because for it the stopping distance is 233.65 m and it takes only 13.8 second to come at rest.

CONCLUSION

For conclusion, an Antilock Braking System (ABS) for quarter vehicle model can be modeled using Matlab SIMULINK. Different controllers can be used for this modeling. But the Fuzzy controller shows a better result compare to PID controller to develop the ABS for the quarter vehicle model. The stopping distance for fuzzy controller is reduced almost 39m from without ABS model. The wheel speed stops at 13.80 second compare to PID controller the wheel stops at 14.090 sec. The slip occurred is ideal at 0.2 for fuzzy controller compare to PID controller which is fluctuating in between 0.1 to 0.3.

REFERENCES

[1] M. C. Wu, and M. C. Shih, "Simulated and experimental study of hydraulic anti-lock braking system using sliding-mode PWM control," Mechatronics, vol. 13, pp. 331–351, 2003.

[2] T. Shim, S. Chang and S. Lee, "Investigation of Sliding-Surface Design on the Performance of Sliding Mode Controller in Antilock Braking Systems," IEEE Trans. Vehicular. Techno, vol. 57, No. 2, pp. 747-759, 2008.

[3] Y. Oniz, E. Kayacan and O. Kaynak, "Simulated and Experimental Study of Antilock Braking System Using Grey Sliding Mode Control," IEEE, pp. 90-95, 2007.

[4] A. Mirzaei, M. Moallem, B. Mirzaeian Dehkordi and B. Fahimi, "Design of an Optimal Fuzzy Controller for Antilock Braking Systems," IEEE Transactions on Vehicular Technology, vol. 55, No. 6, pp. 1725-1730, 2006.

[5] X. Wang, K. W. E. Cheng, X. Liao, N. C. Cheung and L. Dong, "Fuzzy Logic Controller for Electric Vehicle Braking Strategy," PEDS2007, IEEE, pp. 1542-1547, 2007.

[6] A. Mirzaei, M. Moallem, B. Mirzaeian Dehkordi and B. Fahimi, "Design of an Optimal Fuzzy Controller for Antilock Braking Systems," IEEE Transactions on Vehicular Technology, vol. 55, No. 6, pp. 1725-1730, 2006.

[7] A. Mirzaei, M. Moallem and B. Mirzaeian: "Designing a Genetic-Fuzzy Anti-Lock Brake System Controller" IEEE International Symposium on Intelligent Control, Limassol, Cyprus, June 2005.

[8] Hamzah.N, Basari.A.A, "Enhancement of driving safety feature by sliding mode control approach.", Fourth International Conference on Computational Intelligence, Robotics and Autonomous Systems November 28-30, Palmerston North, New Zealand, 2007

[9] Seibum B. Choi, "Antilock Brake System With a Continuous Wheel Slip Control to Maximize the Braking Performance and the Ride Quality.", IEEE Transactions on control system technology, vol. 16, no.5, 2008

[10] S. N. Sivanandam, S. Sumathi and S. N. Deepa "Introduction to Fuzzy Logic using MATLAB" Springer 2007